Integrating information sources for inland waters

A NEW GLOBAL FRAMEWORK FOR LAKES MODELLING AND MONITORING

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ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

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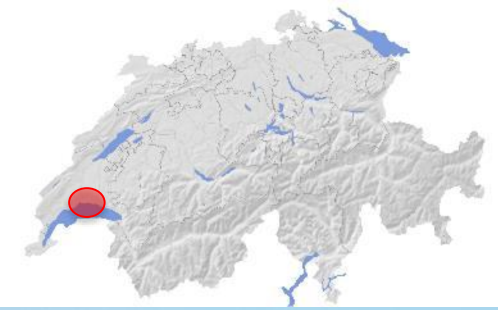


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Outline of the presentation

Motivation

Delft3D - Lakes modelling

OpenDA

- Recent developments
- Delft3D case studies
  - Calibration
  - Data assimilation

Future developments

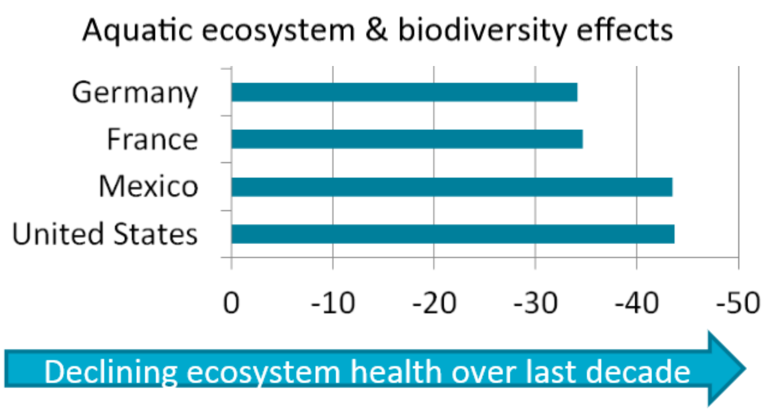
Introduction

“Every lake is a geographical individual well separated from its congeners, in which physical and biological facts develop as in a world apart.”

François-Alphonse Forel,
Le Léman – Monographie Limnologique, 1901

Introduction

|Lakes are “sentinels” of environmental change



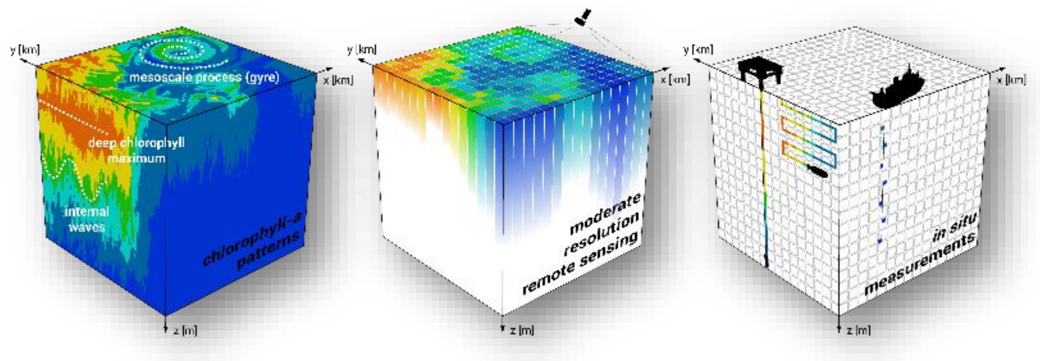
Aquatic ecosystem & biodiversity effects from the Environmental Performance Index [GLaSS project, WorldBank, November 12th, 2013]

A number of policies now aim at securing ecosystem services provided by lakes:

- EU Water Framework Directive
- EU Bathing Water Directives
- EU Nitrates Directive
- UN Post-2015 Development agenda
- …

Introduction

|Existing Monitoring



Model simulation (left), Remote Sensing (RS) observations (center), and *in-situ* measurements [Odermatt & Brockmann GmbH, Zurich Eawag SURF, Kastanienbaum]

3 information sources:

- *In-situ* measurements
- Remote Sensing observations
- Model simulations

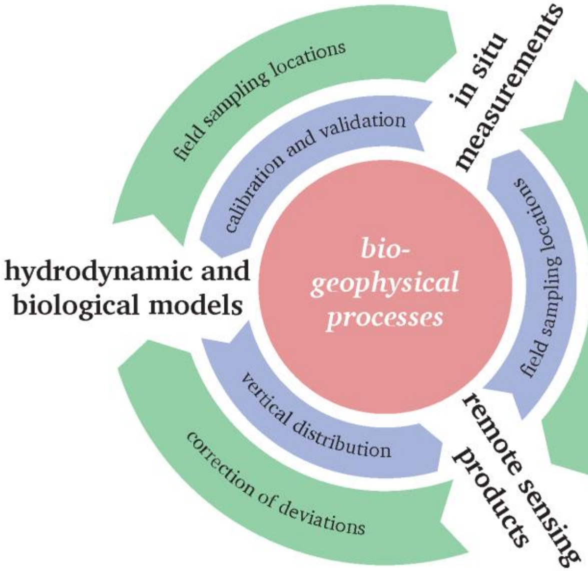
Only a very small proportion of lakes (<0.00003%) are monitored, and when it's the case, often inconsistently

Introduction

Objectives

Provide a modelling framework tailored to inland waters:

- Operational in real-time
- With short-term forecasting
- Online, open to the public
- **Benefiting/applied to aquatic research**
  - By studying mesoscale processes
  - And assessing the variability of lake responses to climate change



Interlink of the 3 information sources

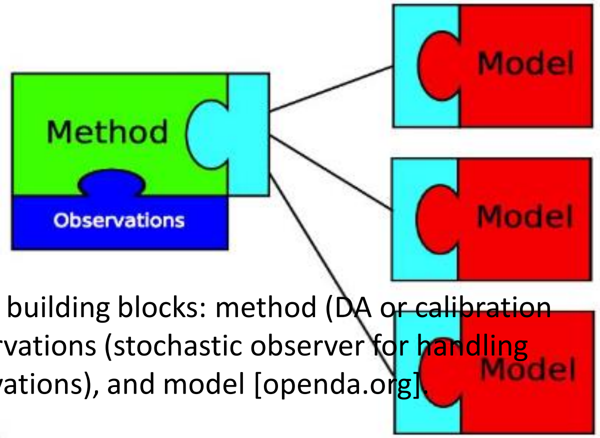
The current challenge is to combine those sources to provide timely, scientifically credible, and policy-relevant environmental information

Motivation

Assimilation platform - OpenDA

Features:

- Open-source
- Various algorithms implemented
- Parallelization possible



OpenDA connects 3 building blocks: method (DA or calibration algorithms), observations (stochastic observer for handling the observations), and model [openda.org].

Implementation:

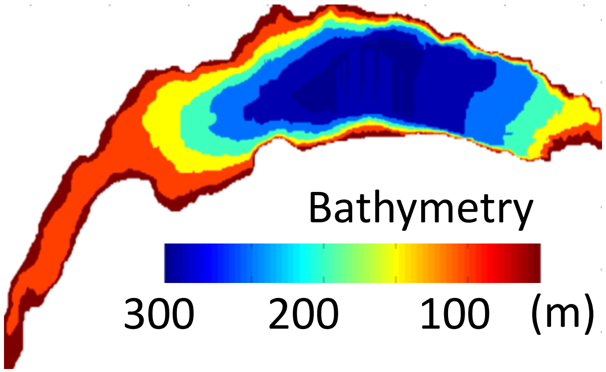
- Communication interface in Java
- Continuing development and testing at Deltares those two weeks

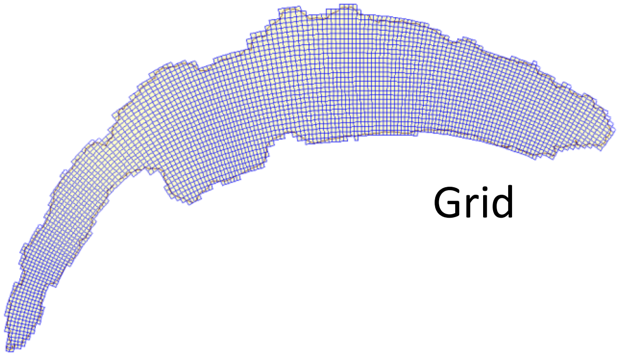
Delft3D – Lakes modelling

| Lake Geneva model setup

Delft3D model set-up:

- *Z-layer, 100 layers*
- < 500m horizontal grid size
- 1 min time step
- Calibrated and validated with in-situ and remote sensing data over two years
- Real time validation with AVHRR satellites



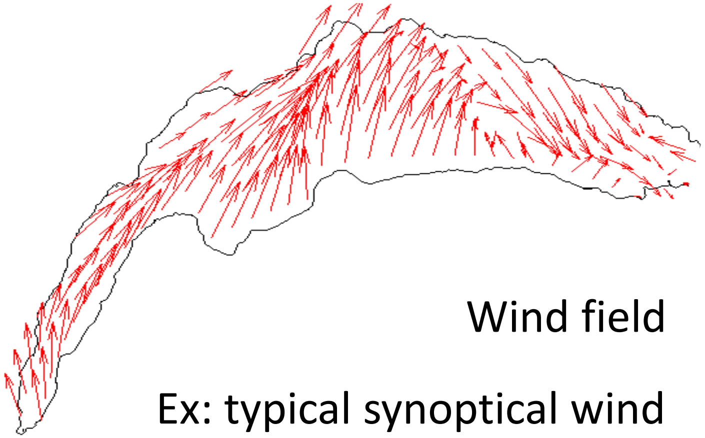


Delft3D – Lakes modelling

| Space-time varying forcing

Meteorological forcing (MeteoSwiss COSMO-1):

- *7 Variables*
  - *Air temperature*
  - *Air pressure*
  - *Relative humidity*
  - *Cloud cover*
  - *Wind intensity*
  - *Wind direction*
  - *Solar radiations*
- Every 1.1 km
- Every hour

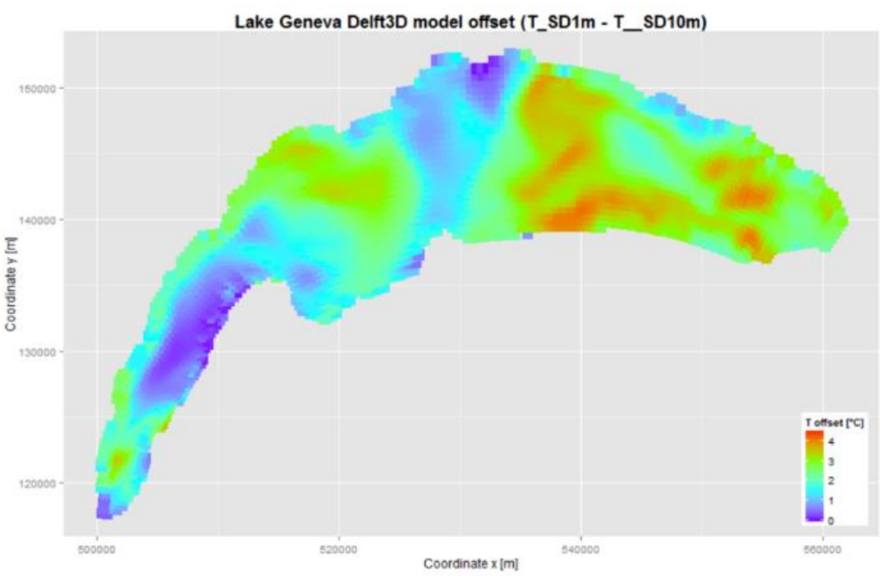


Wind field

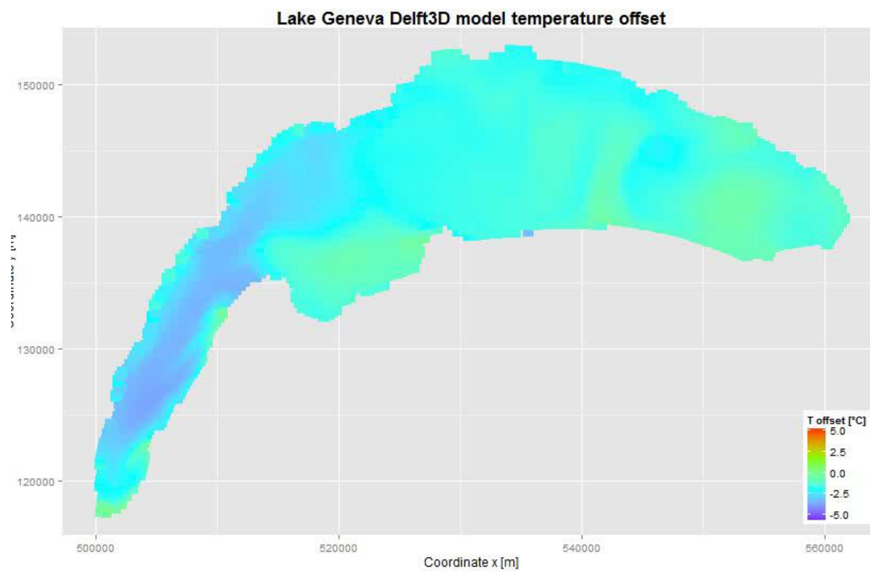
Ex: typical synoptical wind

Delft3D – Lakes modelling

Model limitations and uncertainties



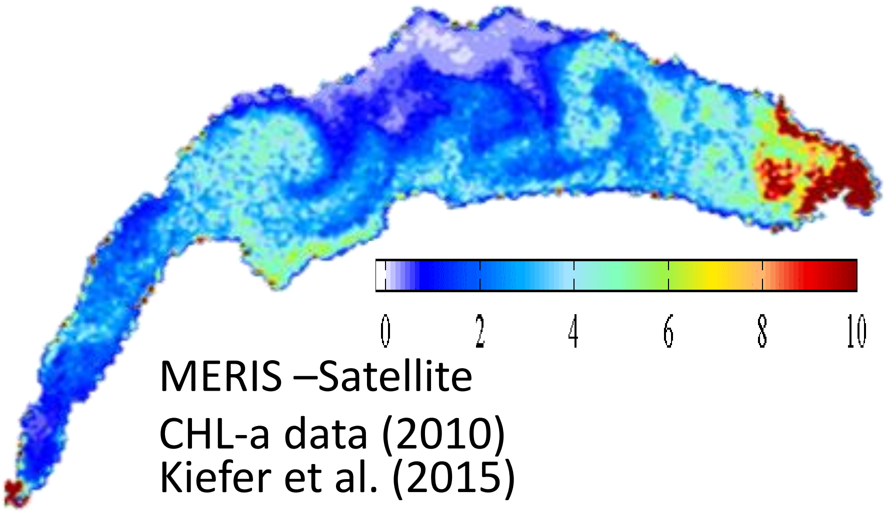
Difference in surface temperature after one month of simulation in summer using a constant **Secchi depth** of 1 m and 10 m.



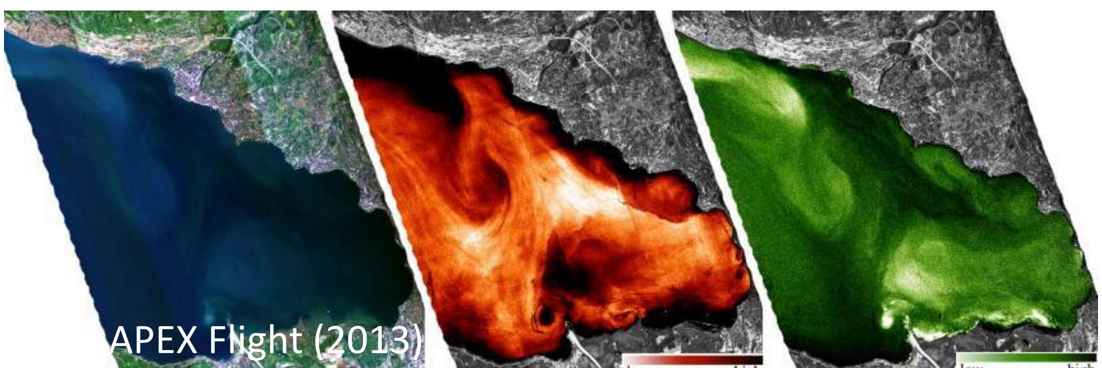
Difference in surface temperature after one month of simulation in summer using a background **horizontal diffusivity** of 0.05 m2/s and 50 m2/s.

Delft3D – Lakes modelling

3D structures



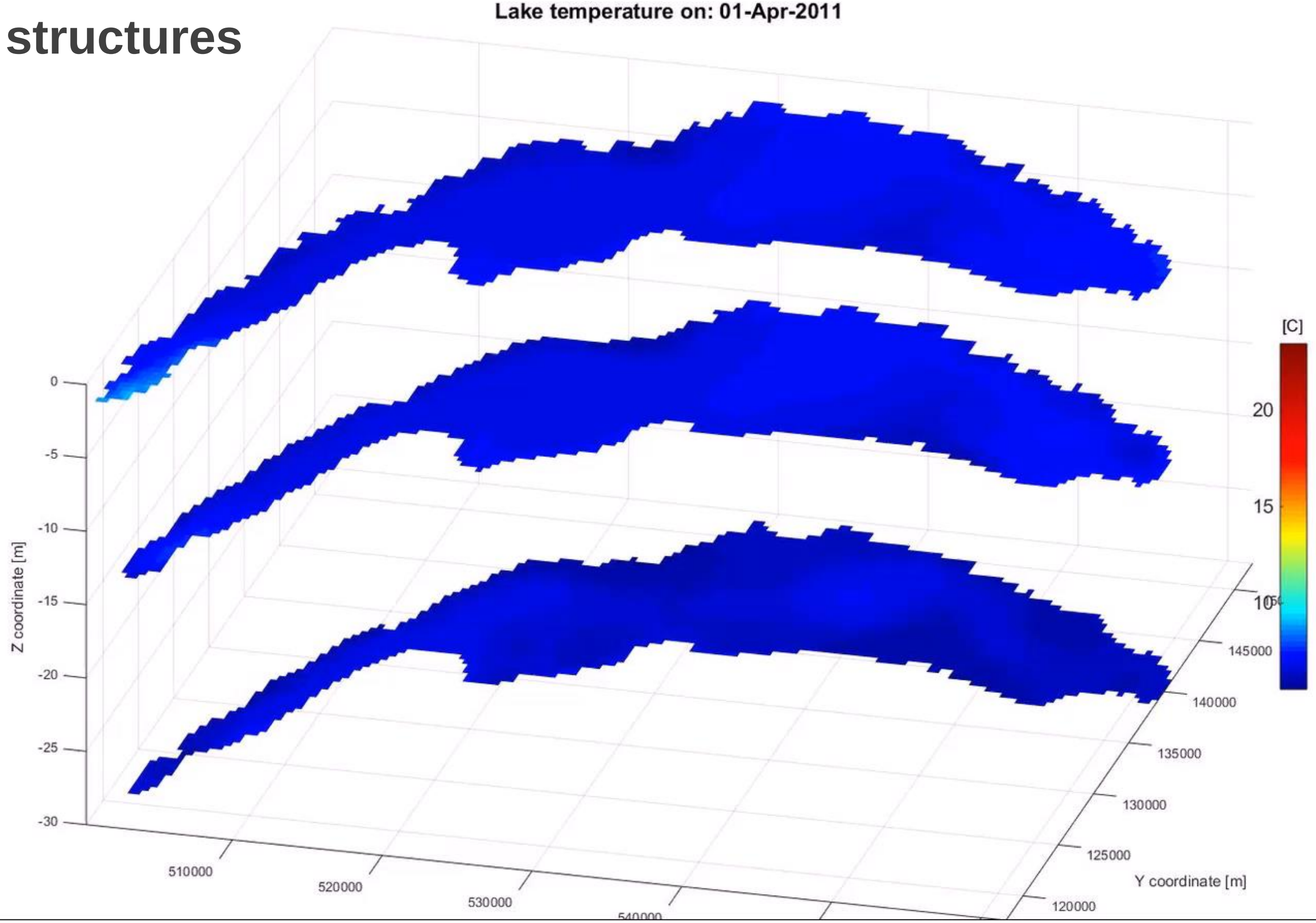
MERIS –Satellite
CHL-a data (2010)
Kiefer et al. (2015)



APEX - true color image
Total suspended solids [mg/l]
Sum of chlorophyll a [µg/l]

Delft3D – Lakes modelling

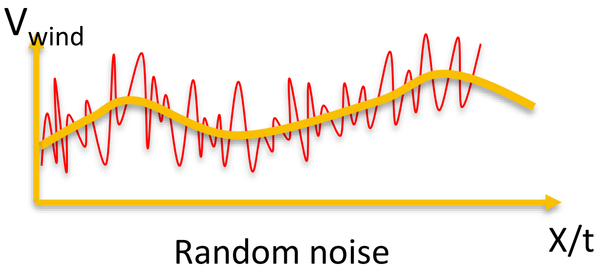
|3D structures

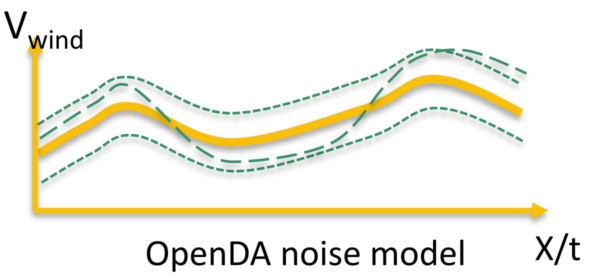


OpenDA – Recent developments

Communication interface with Delft3D

- **Delft3D Flow z-layers** support
- Binary restart and NetCDF history and map files support
- Equidistant space-time varying meteo forcing (wind) support
- State variables
  - Temperature
  - Flow velocities
  - Waterlevels
- 4 parameters
  - Dalton number **c_e** (evaporation/condensation)
  - Stanton number **c_H** (convective heat flux)
  - Background horizontal diffusivity **D_V**
  - Background vertical diffusivity **D_H**

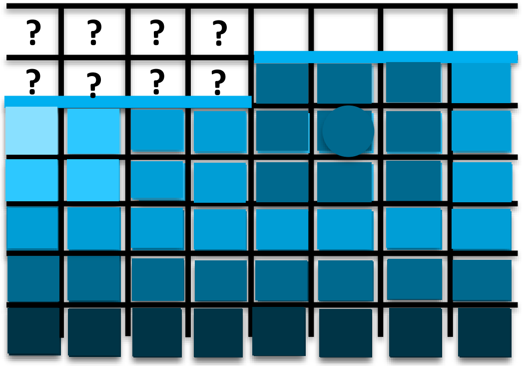


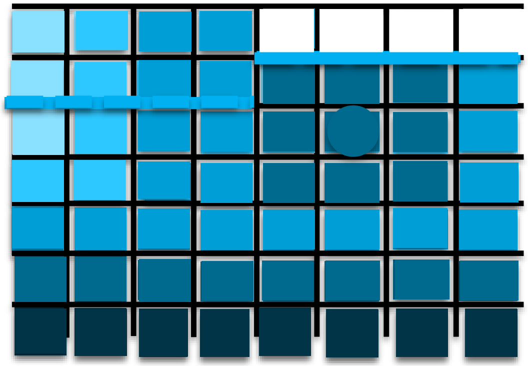


OpenDA – Recent developments

Varying waterlevels implementation

- Domain comparison of ensembles
- Needed when rivers will be included (and strong winds)
- Updating in the fictive domain:

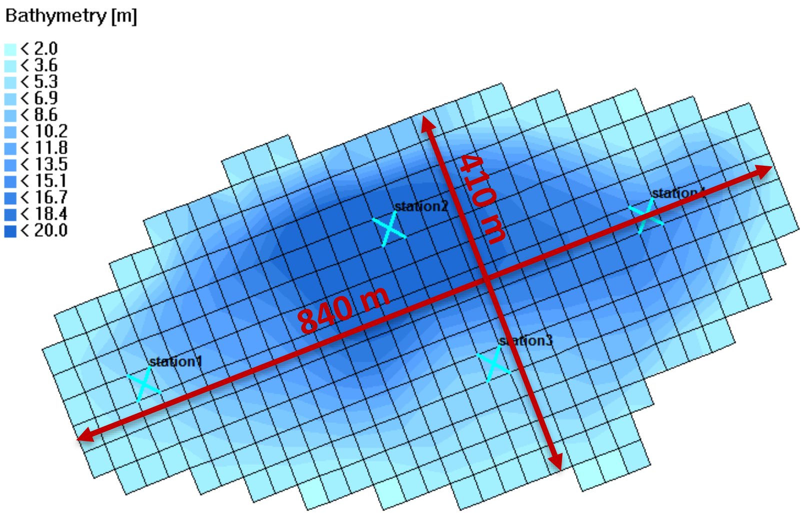




Case studies - Calibration

Twin experiment – Small scale setup

- 25 z-layers (25m x 25m grid)
- Simulation over 2 days
- 4 calibration stations (20 depths)
  - Temperature observations every 30min
  - NetCDF observations file format
- 4 parameters to calibrate
  - Dalton number c_e
  - Stanton number c_H
  - Background horizontal diffusivity D_V
  - Background vertical diffusivity D_H

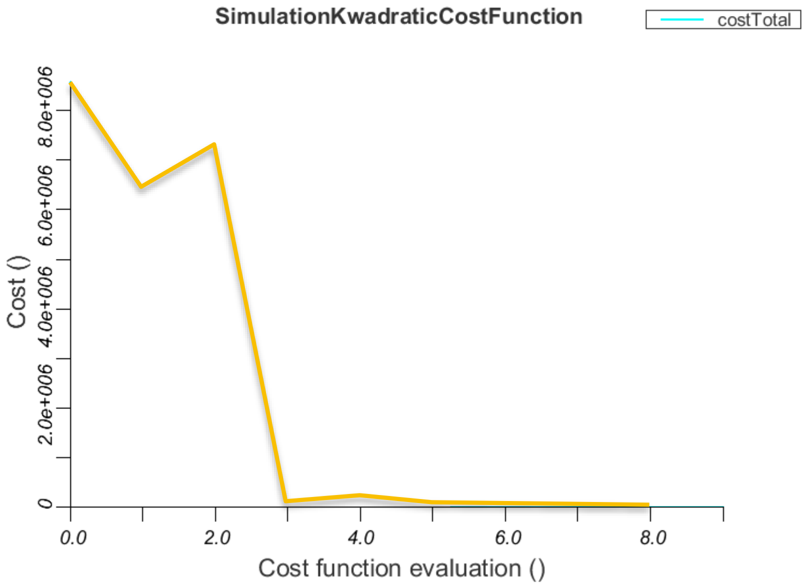


Lake Cadagno

Case studies - Calibration

Cadagno - Simple perturbation

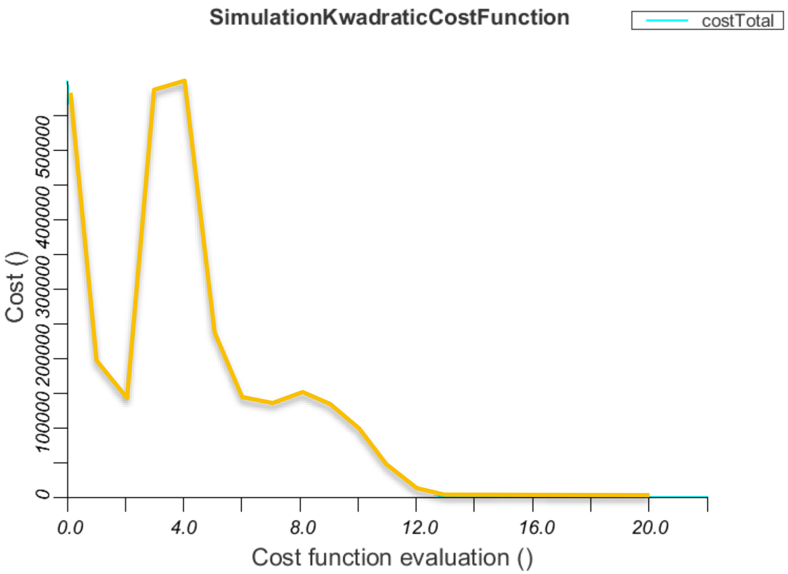
- DUD algorithm (local linearization)
- Perturbation of Stanton and Dalton #
- Results:
  - Stanton [-]: 0.05 -> 0.0013 (truth: 0.0013)
  - Dalton [-]: 0.05 -> 0.0013 (truth: 0.0013)
- Quick to converge towards the true parameter values



Case studies - Calibration

Cadagno – Full perturbation

- Perturbation of all 4 parameters
- Ln transform needed
- Results:
  - Stanton [-]: 0.05 -> 0.013 (truth: 0.0013)
  - Dalton [-]: 0.05 -> 3E-7 (truth: 0.0013)
  - D_V [m2/s]: 1E-5 -> 2.6E-7 (truth: 5E-7)
  - D_H [m2/s]: 0.5 -> 0.47 (truth: 0.1)
- Less successful for Dalton and Stanton #
- Strong dependence on initial stoch. setup

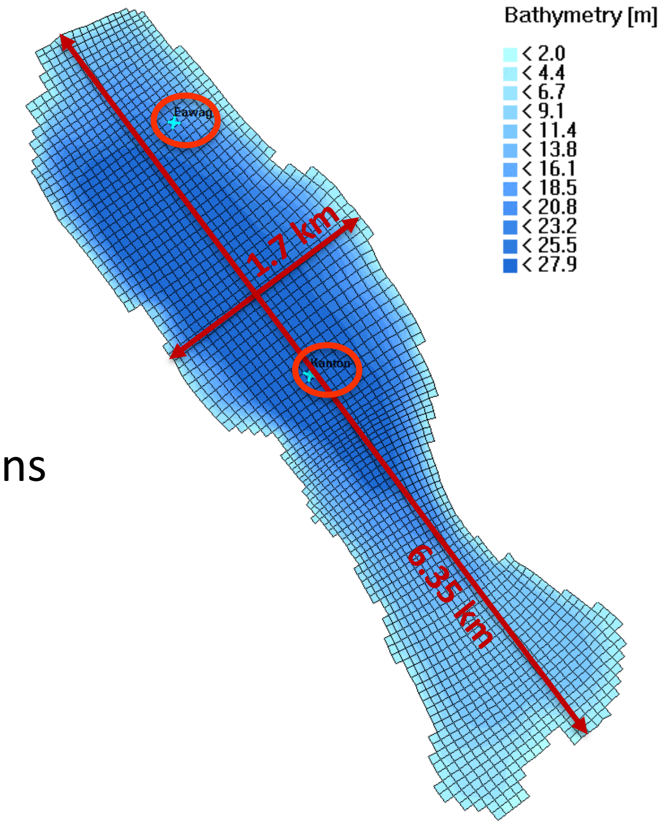


Iteration	Cost	Stantn	Dalton	Dicoww
1	6.74E5	0	0	0
2	2.576E5	-2	0	0
3	1.946E5	0	-2	0
4	6.371E5	0	0	-2
5	5.929E6	2.125	-5.807	-1.656
6	1.104E6	1.063	-3.903	-0.828
7	4.289E5	0.531	-2.952	-0.414
8	2.765E5	0.266	-2.476	-0.207
9	2.285E5	0.133	-2.238	-0.104
10	1.822E5	-0.066	-1.881	0.052
11	1.064E8	5.507	-6.263	0.213
12	4.098E5	-2.853	0.31	-0.029
13	1.798E6	1.327	-2.977	0.092
14	8.608E4	-0.763	-1.333	0.032
15	2.939E4	-1.153	-1.621	-0.436
16	2.71E3	-1.368	-2.531	-1.256
17	378.591	-1.379	-3.195	-1.76
18	40.494	-1.351	-3.887	-2.26
19	26.166	-1.334	-4.209	-2.49
20	26.632	-1.334	-4.183	-2.471
21	26.013	-1.333	-4.223	-2.5
22	26.024	-1.336	-4.268	-2.535
23	26.625	-1.332	-4.2	-2.482
24	25.898	-1.334	-4.234	-2.509
25	25.746	-1.339	-4.219	-2.501
Optimum	25.74626	-1.33892	-4.21896	-2.50097

Case studies - Calibration

Medium scale – setup

- 50 z-layers (60m x 60m grid)
- 6 months simulation
- 4 parameters calibrated
- 2 in-situ temperature measurement stations
  - Low (1/month) and high frequency (1/2h)
  - Over whole water column
  - Noos time-series observations file format

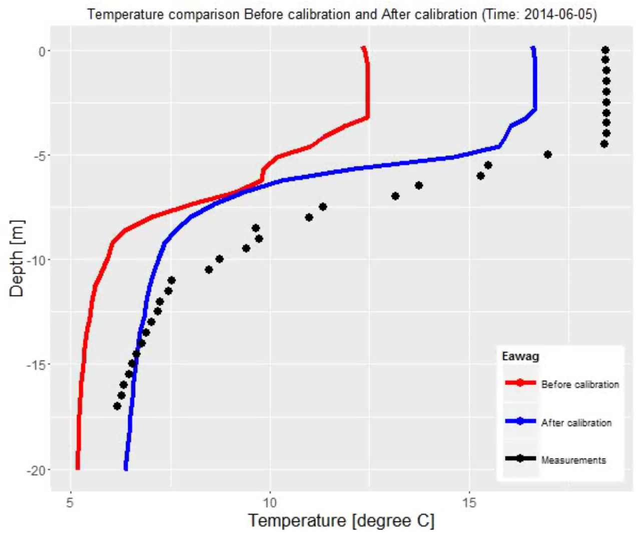


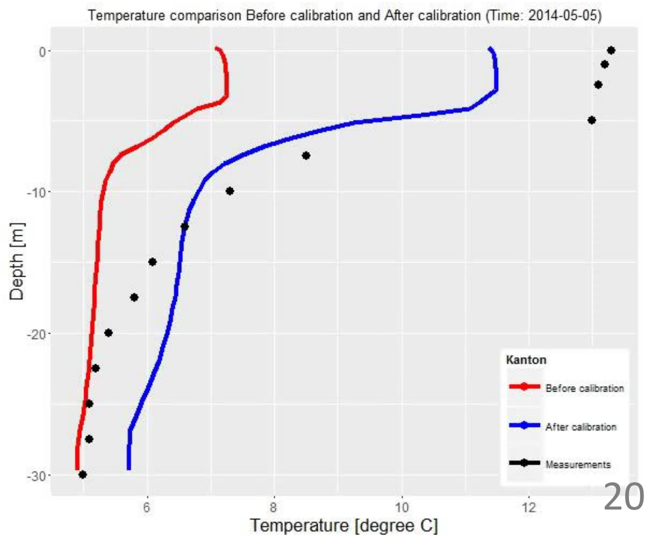
Lake Greifen

Case studies - Calibration

Greifensee – Temperature evolution

- Results:
  - Stanton [-]: 0.01 -> 0.009
  - Dalton [-]: 0.01 -> 0.01
  - D_V [m2/s]: 5E-7 -> 6.9E-8
  - D_H [m2/s]: 1E-3 -> 4.5E-8
- Improved stratification
- Better shallow water temperature accuracy
- Meaningful parameter results

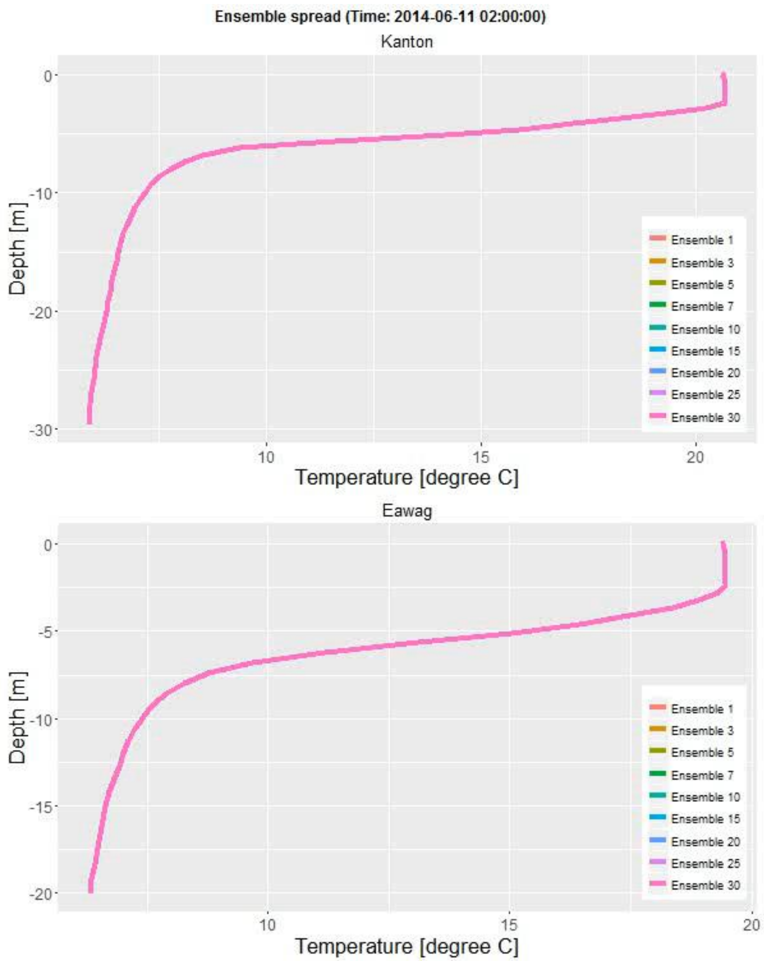




Case studies – Data assimilation

EnKF – In situ data

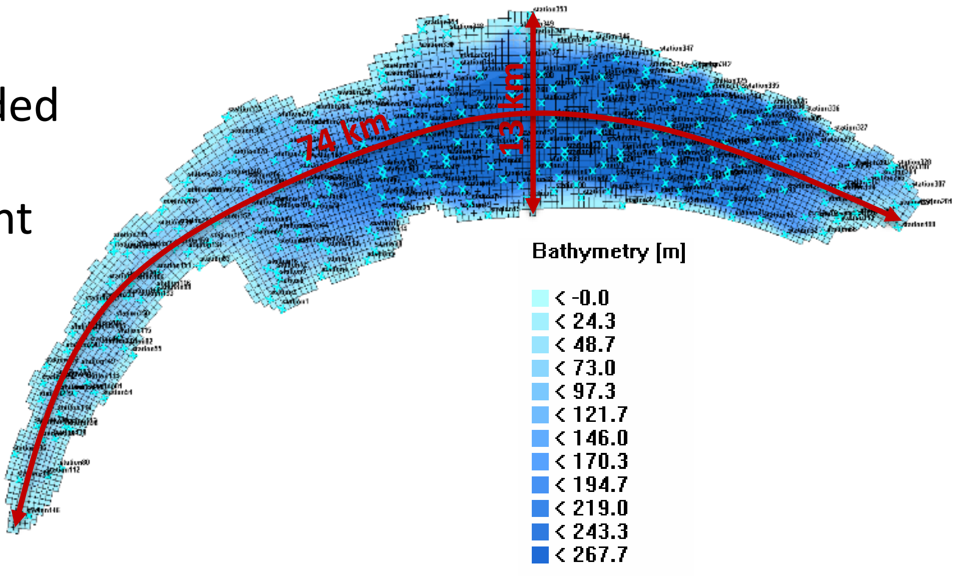
- 31 ensembles
- Temperature assimilation
  - 2 stations, each over whole water column
- Over 2 summer months
- Noise applied to 2D wind forcing
- Work in progress…



OpenDA - Future developments

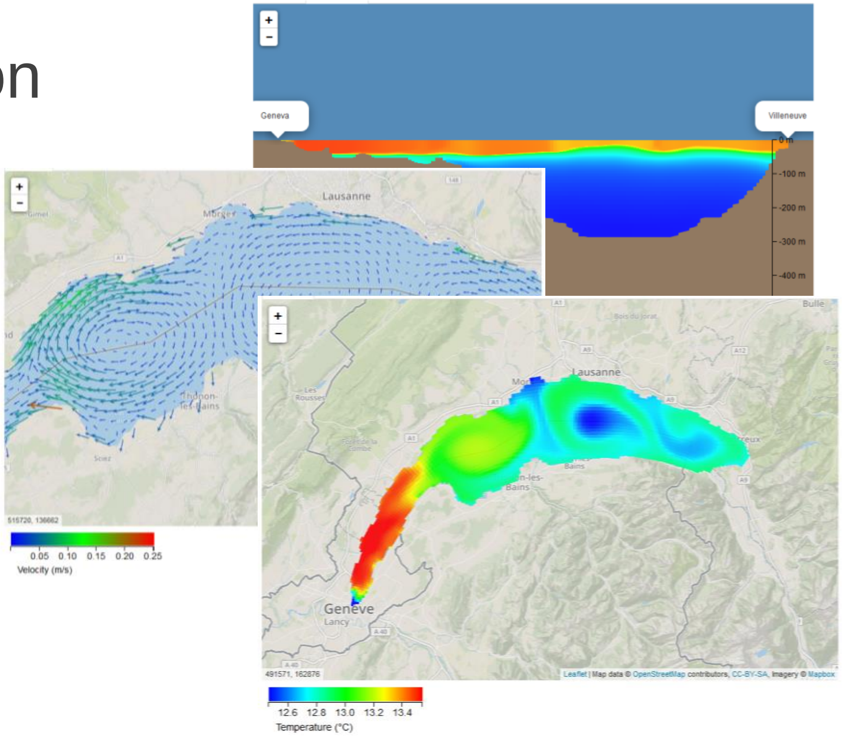
| EnKF – Remote Sensing data

- AVHRR lake surface temperature observations over whole surface
- Localization implementation needed
- Surface echangeItem to implement
- Noise model for other variables (e.g. secchi depth)
- Interface for Delft3D-WAQ (e.g. Chl-a assimilation)



Future developments - Application

| Meteolakes - Online real-time platform



System operation:

- Daily computations (hydrodynamics + water quality)
- 33h forecasts (soon 5d)
- Real-time DA

Applications:

- *Scientists*: in-situ measurements planning, understanding 3D physical phenomenon (e.g. upwellings)
- *Governmental agencies*: monitoring lakes at every location in space and time, following the stratification and mixing
- *Public awareness:* 50 daily users on avg., up to 800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